Developing Reservoir Operational Plans to Manage Erosion and Sedimentation during Construction, Willamette Temperature Control - Cougar Reservoir 2002 – 2003.

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Abstract

Construction projects at reservoir sites may create additional erosion and increase sedimentation into the reservoir pool. Impacts to water quality below the reservoir following the resulting increase in sediment discharge may degrade aquatic habitat and reduce recreational resource values. Construction of the Cougar Reservoir portion of the Willamette Temperature Control Project required the reservoir pool to be lowered 132 feet below its normal minimum pool for the construction season. The drawdown of the reservoir pool created substantial erosion and adversely affected water quality in the South Fork McKenzie and mainstem McKenzie rivers downstream of the project, causing much public concern. The development of a reservoir operational plan to minimize the effects of the ongoing construction activities and potential for increased erosion is presented.

Introduction

Cougar Reservoir (Figure 1) is an existing federal reservoir project located in the watershed of the McKenzie River of western Oregon. The project is located on the South Fork of the McKenzie River 4.4 miles upstream from the confluence with the McKenzie River. The project is 42 air miles east of Eugene, Oregon, off of Highway 126 and 61 river miles upstream from the mouth of the McKenzie River. The McKenzie River originates in the upper elevations of the Cascade Mountains, flowing in a generally westerly direction to enter the Willamette River at River Mile (RM) 170.8 near Eugene. Cougar Reservoir provides flood control and supplemental downstream flows for irrigation, navigation, fisheries, pollution abatement, recreation and power generation (USACE, 1998)

The purpose of the Willamette Temperature Control (WTC) project is to modify temperatures for the Cougar and Blue River Reservoirs with the objective of replicating pre-reservoir water temperatures on the South Fork of the McKenzie River and on Blue River, below the reservoirs, and on the mainstem McKenzie River. The first phase of the project began at Cougar Reservoir in August 2001.

Figure 1 - Cougar Reservoir.

Background

At full pool, (El. 1699) Cougar Reservoir is about 6.5 miles long, 0.7 miles wide at maximum width, and has a surface area of 1280 acres. Cougar Dam is a rock-fill embankment about 1600 feet long and 450 feet high from average tailwater to the crest of dam at elevation 1705 feet. The regulating outlet and penstock tunnels are located in the left abutment and have a common intake structure. Construction of the new 302-foot tall intake tower will be attached to the upstream side of the existing intake structure. Adjacent to the construction site (Figure 3), a drainage culvert and outlet was placed at Rush Creek, which drains into the lower pool. A cofferdam was constructed to elevation 1495 feet to protect the construction site from flooding. The original diversion tunnel used in construction of Cougar Reservoir was reopened in February 2003 to provide for reservoir operations during construction of the new multilevel intake structure. At the start of the construction period, the pool was lowered 132 feet from its normal minimum of 1532 feet and maintained at that level to provide habitat for the remaining fish and to reduce sediment releases downstream. The construction pool level of 1400 feet reduces the risk of overtopping the cofferdam and flooding the construction site. Figure 2 below shows the normal operational pool levels.

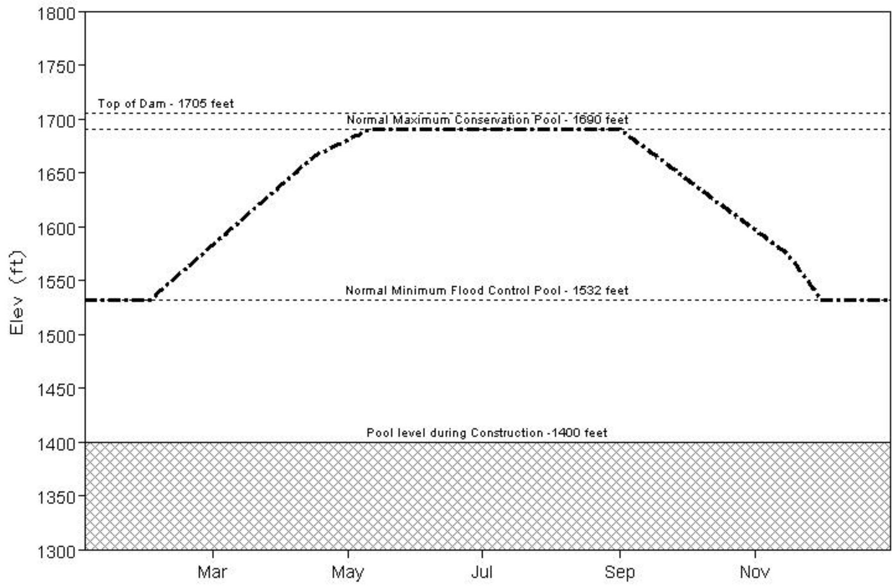

Figure 2 - Normal and Construction pool elevations for Cougar reservoir.

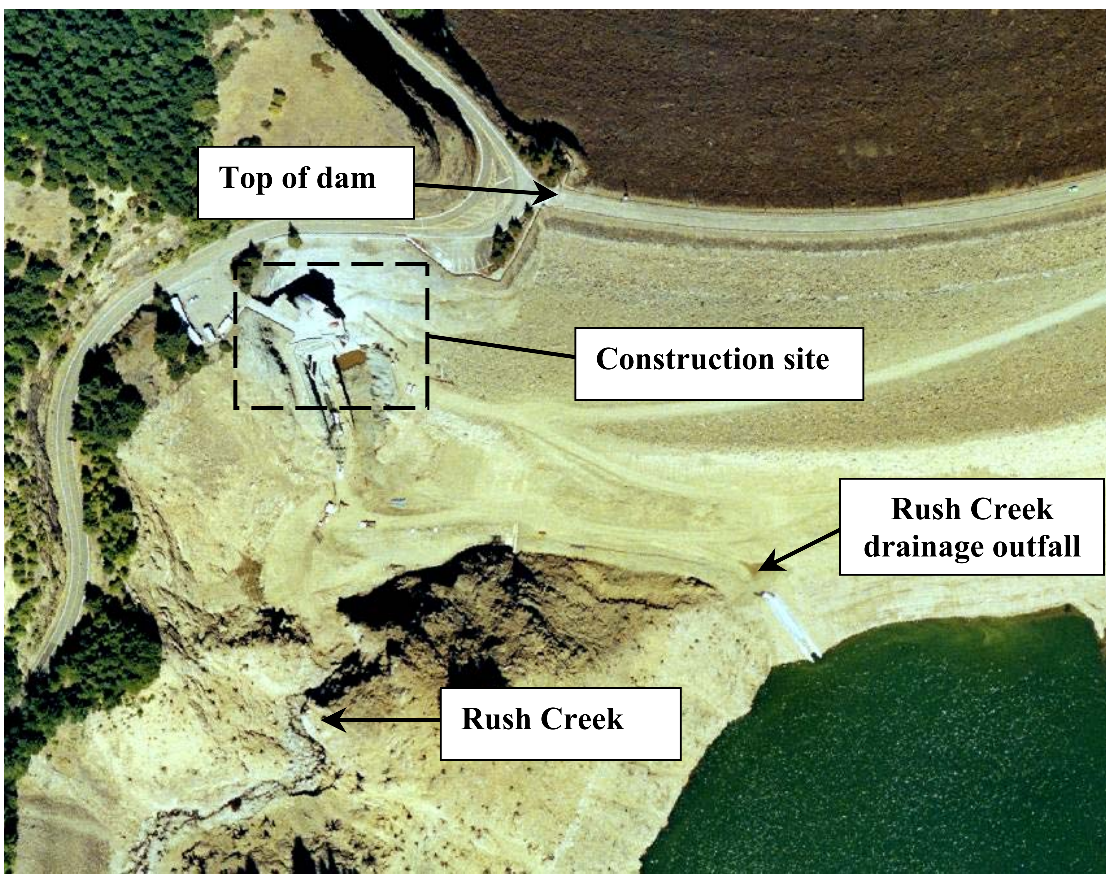

Figure 3 - WTC - Cougar construction site. Reservoir pool elevation 1400 feet.

Initial drawdown of Cougar Reservoir

Modifications to the diversion tunnel started in August 2001 and were completed when the last part of the concrete plug sealing the tunnel was opened on February 23, 2002. As the last of the concrete plug was blasted out, a torrent of 3,500 cfs of water from the bottom of the reservoir roared out of the tunnel and down the South Fork McKenzie. Drawdown of Cougar continued at a rate of 3 feet per day, a conservative rate designed to minimize bank and slope failures. The drawdown of the reservoir ended on May 26, 2002 when the pool reached 1400 feet. Extended high levels of turbidity occurred as a result of the high amount of sediment discharged during the drawdown process. Figure 4 shows the pool elevation, releases and turbidity measured immediately downstream of the project. Severe economic and environmental consequences occurred downstream of the reservoir as a result of the extended high levels of turbidity. (USACE, 2003). Normal turbidity in the South Fork and mainstem McKenzie Rivers below Cougar Reservoir is typically very low, form 0 to 10 NTU, and rarely exceeds 50 NTU.

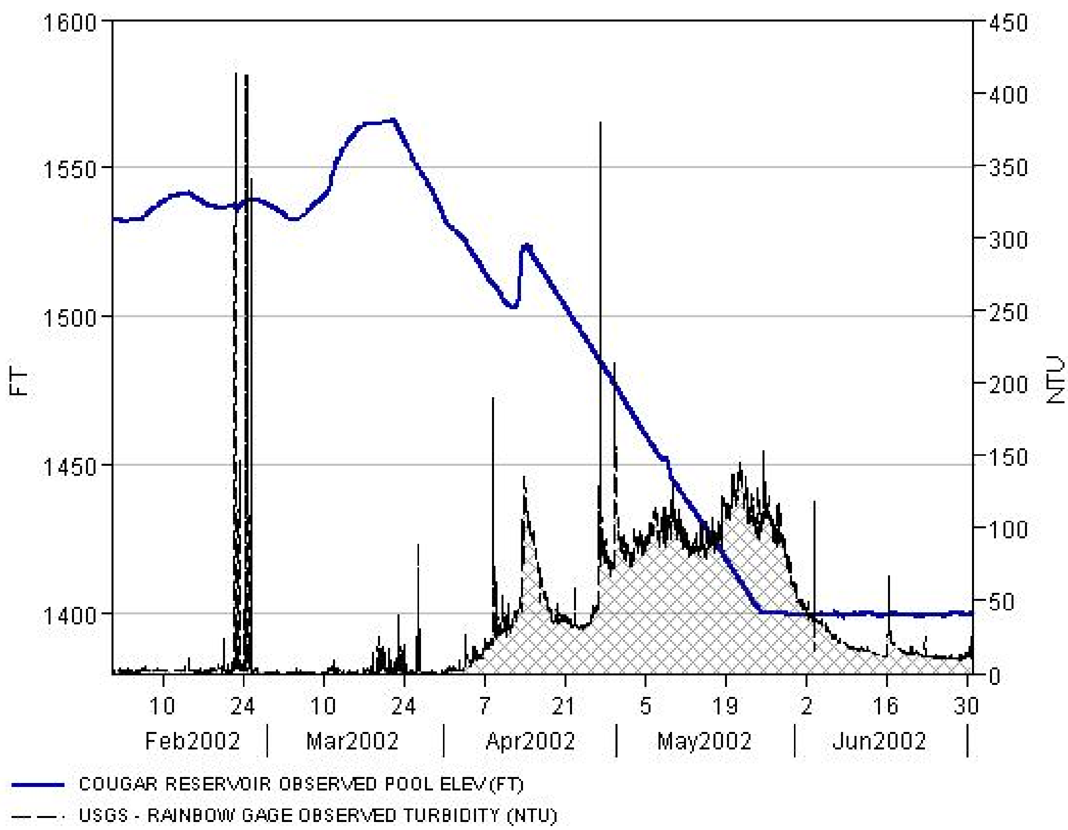

Figure 4 - Measured turbidity downstream of Cougar Reservoir vs. pool elevation and releases - February 1 to July 1, 2002.

Erosion and Sediment Transport during initial drawdown of Cougar Reservoir

Drawdown of Cougar Reservoir below its normal minimum pool level of 1532 feet to the construction pool level of 1400 feet resulted in substantial erosion of exposed unvegetated soil and deposited sediments within the reservoir. The major tributary drainage streams flowing into the reservoir, the South Fork McKenzie, East Fork McKenzie, and Walker Creek, re-established channels to the lower pool at the 1400 foot level. These processes transported large amounts of sediment into the newly created lower pool area at 1400 feet. Detention time in the construction pool was sufficient to allow the bulk of the coarser grained sediment mass to settle out. Much of the fine grained sediment mass (silt-clay fraction, grain size smaller then 62 microns) remained in suspension and was released from the reservoir over the period from April 1 to May 25, 2002 when the pool level reached 1400 feet.

The fine-grained material released from the reservoir caused extended elevated turbidity in the South Fork McKenzie to the confluence and into the mainstem McKenzie Rivers. Visual observation of the South Fork McKenzie River gravel bed below Cougar Reservoir and of the mainstem McKenzie River below its confluence with the South Fork indicated the presence of a thin layer of silty material following the sustained releases of highly turbid water from Cougar Reservoir. Some of the fine sediment in suspension accumulated in the algae covering the gravel bed, changing the color of the algae. The extent of the changes to the streambed are still being evaluated.

Suspended Sediment and Turbidity relationships

In order to assess the environmental impacts of the extended period of high turbidity in the South Fork and mainstem McKenzie Rivers on fishes, estimates of suspended sediment concentration were made by the Corps. Estimates of suspended sediment concentrations over extended time periods in the South Fork McKenzie River below Cougar Dam may be made using the measured turbidity at USGS gage, number 14159500 near Rainbow, Oregon. The gage is located just downstream of Cougar Reservoir.

Equations for Suspended Sediment Concentration (SSC) as a function of turbidity are developed using linear regression methods with SSC as the dependent variable and turbidity as the independent variable. The equations developed are site specific and are typically based on data collected over a wide range of streamflows and basin conditions. Many factors may influence the SSC–turbidity (SSC-T) relationship for any given site, such as the geology of the watershed, soils, vegetation, slope, aspect, and land use (Lewis, et al., 2002). The SSC-T relationship is also affected by the effects of sediment loading over time as exhibited downstream of reservoirs. In general, sediment discharge from reservoirs tends to be higher in fine sediment, as the coarser fraction settles out in the reservoir pool.

To provide estimates of SSC in the South Fork McKenzie River below Cougar Reservoir, the Corps used data from the USGS North Santiam River Basin Suspended-Sediment and Turbidity Study (Urich, et al, 2002). SSC-T relationships were developed for five sites in the North Santiam basin, and provided by the USGS.

After evaluation of the five SSC-T relationships provided, the SSC-Turbidity relationship at Mehama, OR (USGS gage 14183000) was used to develop SSC and sediment discharge estimates for the South Fork McKenzie River below Cougar Reservoir. Five suspended sediment samples taken below Cougar over a six week period during the initial drawdown were compared with the corresponding turbidity readings when the samples were taken. The SSC-T relationship of the samples compared most favorably with the Mehama data.

The Mehama, OR location was selected because it represented a site located below a reservoir (Detroit), and because of the similarity in geology of the North Santiam and South Fork McKenzie watersheds. Because the SSC-T relationships are watershed and site specific, use of the Mehama data to estimate SSC and sediment discharge below Cougar Reservoir provide, at best, a gross estimate.

The computed mean suspended sediment concentration over the period from April 9 to June 6, 2002, was 48.5 mg/liter; the corresponding average turbidity was 76.1 NTU. The computed sediment discharge was approximately 12,500,000 kg (13,800 tons). Applying a standard error, the estimate is between 4,530,000 kg (5,000 tons) and 20,500,000 kg (22,600 tons).

Development of reservoir operational plan after initial drawdown

The primary goals of the reservoir operational plan during construction were to be at the target pool elevation of 1400 feet by the start of the construction season on April 1, 2003 and not to elevate turbidity levels below the dam in the South Fork and maintstem McKenzie rivers during the spring trout fly fishing season. The high levels of turbidity which occurred in the South Fork McKenzie River below Cougar from February to June 2002 were caused by the initial drawdown of the reservoir pool 132 feet from its minimum operating pool level of 1532 feet.

The operational plan is one of several Best Management Practices (BMP's) implemented to reduce turbidity downstream. Although turbidity levels downstream of the dam are largely affected by releases from Cougar, turbid flows may also enter the South Fork and mainstem McKenzie from tributary streams below the dam and contribute to turbidity level. Reduction of turbidity levels within the reservoir by minimizing erosion and sediment resuspension processes will ultimately reduce turbidity downstream.

Three operational strategies were identified with the potential to reduce the turbidity occurring downstream of Cougar during the construction project. The reservoir would still be operated for flood control if additional flood storage were needed downstream. The options are:

1. Increasing the drawdown rate of the reservoir pool below its normal minimum pool of 1532 feet. A limit of 3 ft/day was used in the initial drawdown plan, a conservative limit designed to minimize slope failures. The limit was raised to 6 ft/day. The rate increase would enable the reservoir to be cleared of turbid water more rapidly and decrease the duration of the elevated turbidity levels downstream of the reservoir.

2. Adjusting the winter flood control/non-construction pool elevation. The two options were to raise the pool back to its normal minimum pool of 1532 feet or attempt to hold the pool at the construction pool elevation of 1400 feet. These were referred to as high pool (HP) and low pool (LP) options. Figure 5 shows the areas submerged for both options.
3. Adjusting the target date to reach the construction pool level of 1400 feet. The two options considered were March 1 and April 1, the normal start of the construction season.

These strategies were combined into six operational alternative plans. Table 1 summarizes the operational plans studied.

Table 1 - Alternative reservoir operational plans for operation of Cougar reservoir during WTC construction.

Alternative	Target date	Drawdown rate	Winter Pool Elev.
LP1	-	3 ft/day	1400 ft
LP2	-	6 ft/day	1400 ft
HP1	March 1	3 ft/day	1532 ft
HP2	April 1	3 ft/day	1532 ft
HP3	March 1	6 ft/day	1532 ft
HP4	April 1	6 ft/day	1532 ft

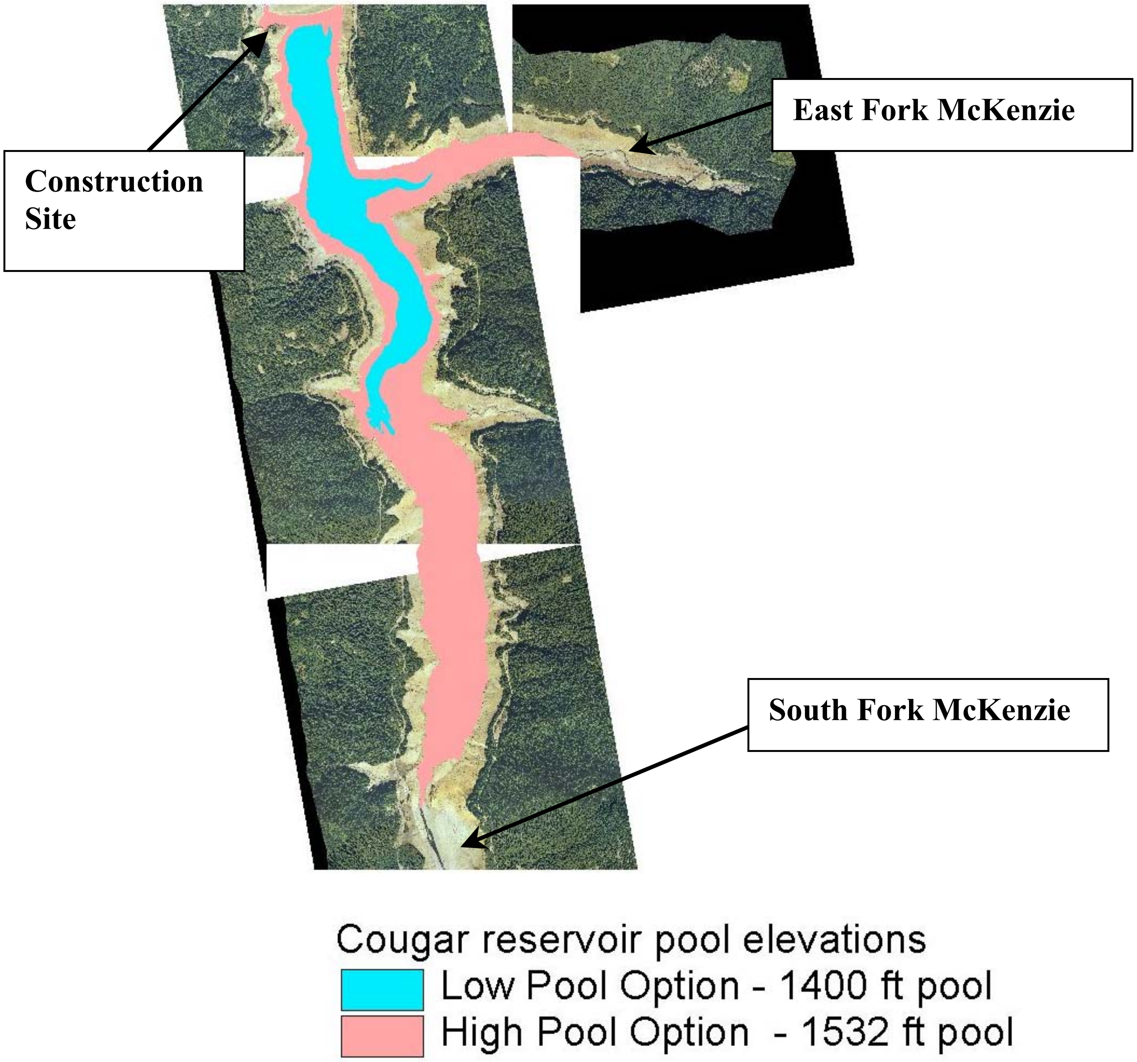

Figure 5 - Cougar Reservoir pool elevations, showing areas underwater for the two alternative pool levels.

Advantages and disadvantages for maintaining the pool during the winter flood control /non-construction period at or near elevation 1400 feet are listed below.

Advantages:

- Widening and armoring of South Fork McKenzie channel formed to the 1400 foot level during the initial drawdown over the winter period and beyond. This would allow the channel to become more established, reducing the risk of a new channel forming and cutting through the fine sediment deposits exposed at the 1400 foot pool elevation.
- Higher probability of reaching elevation 1400 by March 1 if there is a high-water event during the winter. This is because of the lower pool elevation prior to the high-water event (i.e., there is a higher probability of having a lower pool elevation after storing a flood).

- During the winter, the timeframe for flushing turbid water from the pool would be shorter because of the lower volume and detention time.
- Vegetation established below 1532 feet during summer 2002 would not be drowned out, and would become better established. This would reduce erosion in the lower pool, thereby reducing sources of turbidity within the reservoir. Turbidity in succeeding years during construction should decrease.

Disadvantages:

- Likely higher turbidity during the winter. There may be an increased number of turbidity events and increased turbidity associated with each event due to migration of the South Fork McKenzie and other tributary streams at the 1400 foot level. Rapid rises in the pool level during winter storms will result in erosion of exposed sediments, and slope failures.

Advantages and disadvantages for filling the reservoir to its normal winter flood control pool at elevation 1532, then drawing it back down again in mid-January are listed below.

Advantages:

- Reduced probability of turbid flows below the dam during the winter if the reservoir fills with clear water, or following clearing of turbidity from the reservoir after it fills.
- Reduced or more normal winter turbidity downstream of Cougar reservoir during the filling period.

Disadvantages:

- Increase in risk that a new channel could be formed during the drawdown back to 1400 ft. The new channel would cut through erodable material in the mid pool area transporting more material to the lower reservoir pool, increasing turbidity of the pool overall.
- Higher risk of increased turbidity below the dam during the spring as sediment redistributed and deposited in the reservoir channel during inundation is resuspended during drawdown.
- Lower probability of reaching 1400 by March 1 if there is a mid-January or mid-February high-water event. A high-water event in mid-January or mid-February would impact the timing and duration of drawdown increasing the chance of turbid flows in the spring.
- Longer timeframe for flushing turbid water from the reservoir over winter because of the larger volume and longer detention time. However, turbidity would not peak as high.

In order to assess the potential effects of the six proposed operational plans on the McKenzie River system and Blue River Reservoir, system analysis was performed using HEC ResSim, a computer model capable evaluating the proposed operational criteria. HEC ResSim was selected over the more widely used HEC-5 model because of the availablity of an elevation change rule, used to define the drawdown rate alternatives. Simulations of the various alternatives were made using a historical database of daily mean flows from 1935 to 1998. The results of the modeling determined the probability of reaching the target construction pool on March 1 under the six alternatives. Table 2 summarizes the results.

Table 2 Cougar Reservoir pool elevations (ft), 10 - 90 percent non-exceedance probabilities at March 1

	10 %	25%	50%	75%	90%
HP1	1404	1405	1412	1443	1483
HP2	1454	1456	1457	1460	1488
HP3	1401	1403	1406	1412	1455
HP4	1454	1456	1459	1461	1472
LP1	1400	1401	1404	1435	1464
LP2	1396	1400	1403	1407	1447

The two alternatives with the best chance of reaching a pool elevation of 1400 feet are HP3 and LP2. In HP3, when the reservoir pool is raised to elevation 1532 feet, it would only be maintained at that elevation for about 6 weeks. As such, most of the benefits of keeping the reservoir pool at elevation 1532 feet may not be realized. In addition, the difference between the two alternatives is only significant for an average or below average water year. An above average water year does not significantly favor either alternative. Given the number of advantages for maintaining the reservoir pool at or near elevation 1400 feet, the preferred operational alternative is to keep the pool at or near elevation 1400 ft for the duration of the construction project using a drawdown rate of 6 ft/day below elevation 1532 ft (LP2).

Erosional processes occurring within the reservoir after initial drawdown

Four erosional processes occurring within the reservoir after the initial drawdown of Cougar to elevation 1400 feet are responsible for movement and resuspension of sediment into the residual pool. These processes contribute to turbidity in the reservoir and downstream. The turbidity level measured immediately downstream of the reservoir is very close to the turbidity level within the reservoir.

1. Submergence of dried lakebed or mudflats found in broad alluvial fan deposits. These lakebed deposits (Figure 6) had dried over the summer, exposing very fine material. This material is readily detachable by flowing water in the initial dry state and, when submerged by the rapid rise in pool level causes a sharp corresponding rise in turbidity. Several storms occurred in late December 2002 which raised the reservoir elevation to 1411 feet on December 31, 2002 and 1413 feet on January 5, 2003. Figure 8 shows the areas in the reservoir submerged for a rise in the pool from 1402 to 1412 feet.

The highest turbidity (Figure 7) occurred on December 31 at 202 NTU. Turbidity levels rose again and reached 117 and 113 NTU on January 3 and 5, 2003 respectively.

Figure 6– Lakebed deposits, Cougar Reservoir August 2002.

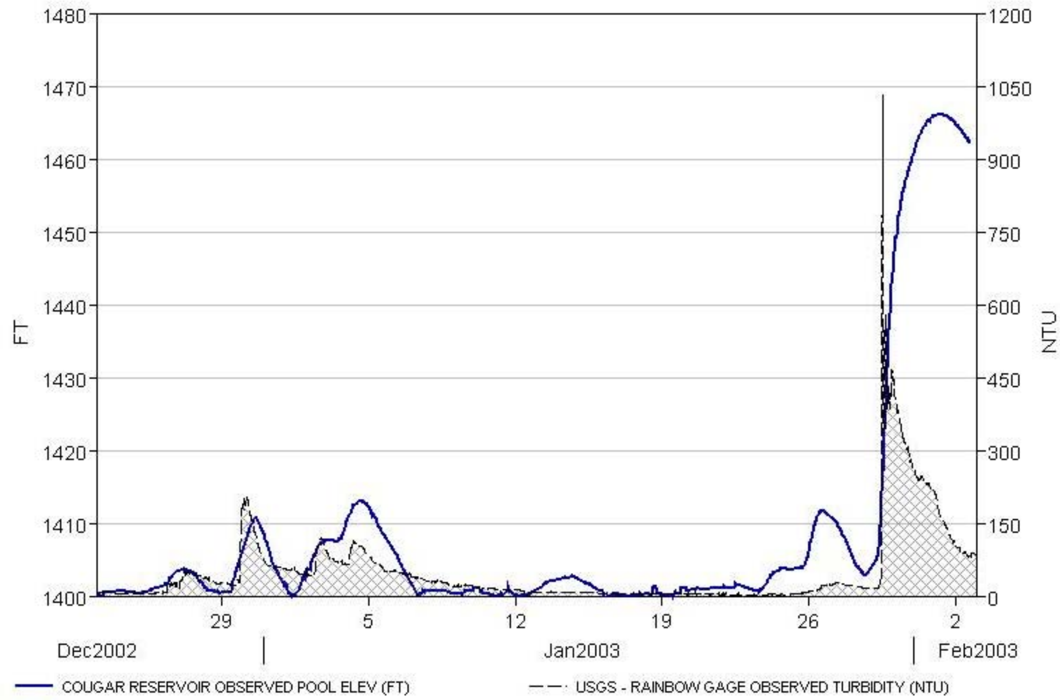

Figure 7 -- Observed Cougar Reservoir elevation December 2002 – February 2003. Observed discharge and turbidity USGS gage 14159500 SF McKenzie near Rainbow, OR

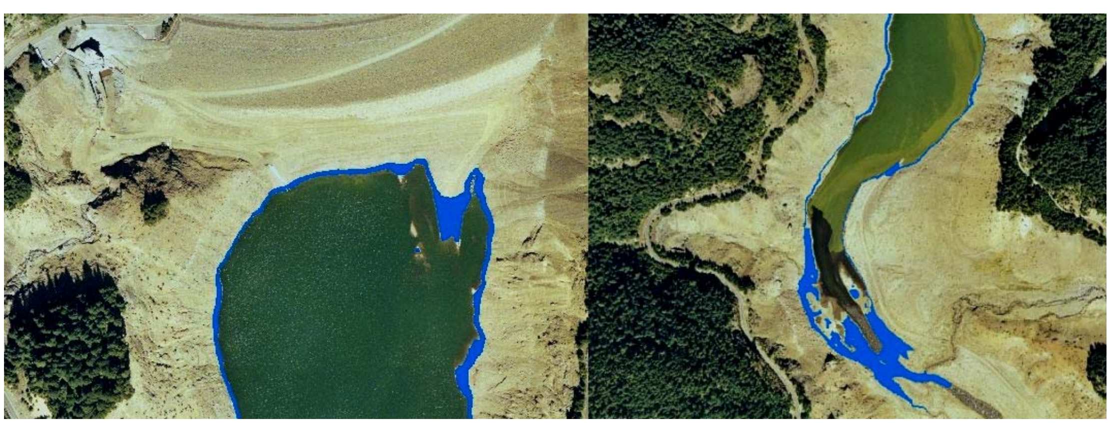

Figure 8 - Cougar Reservoir. Areas in blue represent elevation 1402 - 1412 feet.

2. Mass wasting and slope failures caused by fluctuating pool levels. Many localized slope failures were observed within the reservoir (Figure 9). These slope failures transport coarse material and little fine sediment. The impact on turbidity is not as great, but slope failures are a hazard.

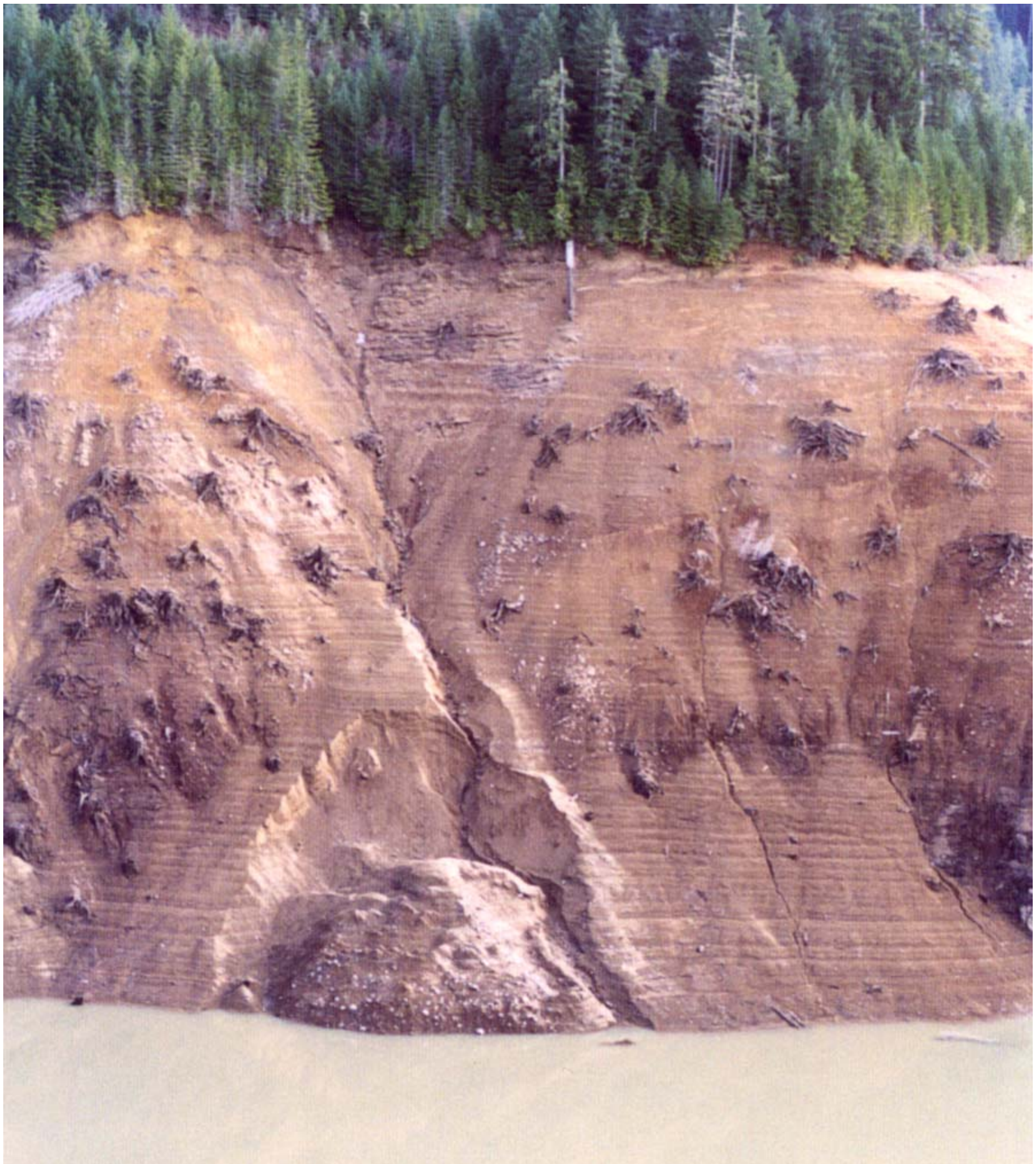

Figure 9 - Typical slope failure at pool elevation 1450 feet. Photo by Chauncey Anderson (USGS) February 2003.

3. Active erosion of clay banks found in the mid pool area. (Figure 10)

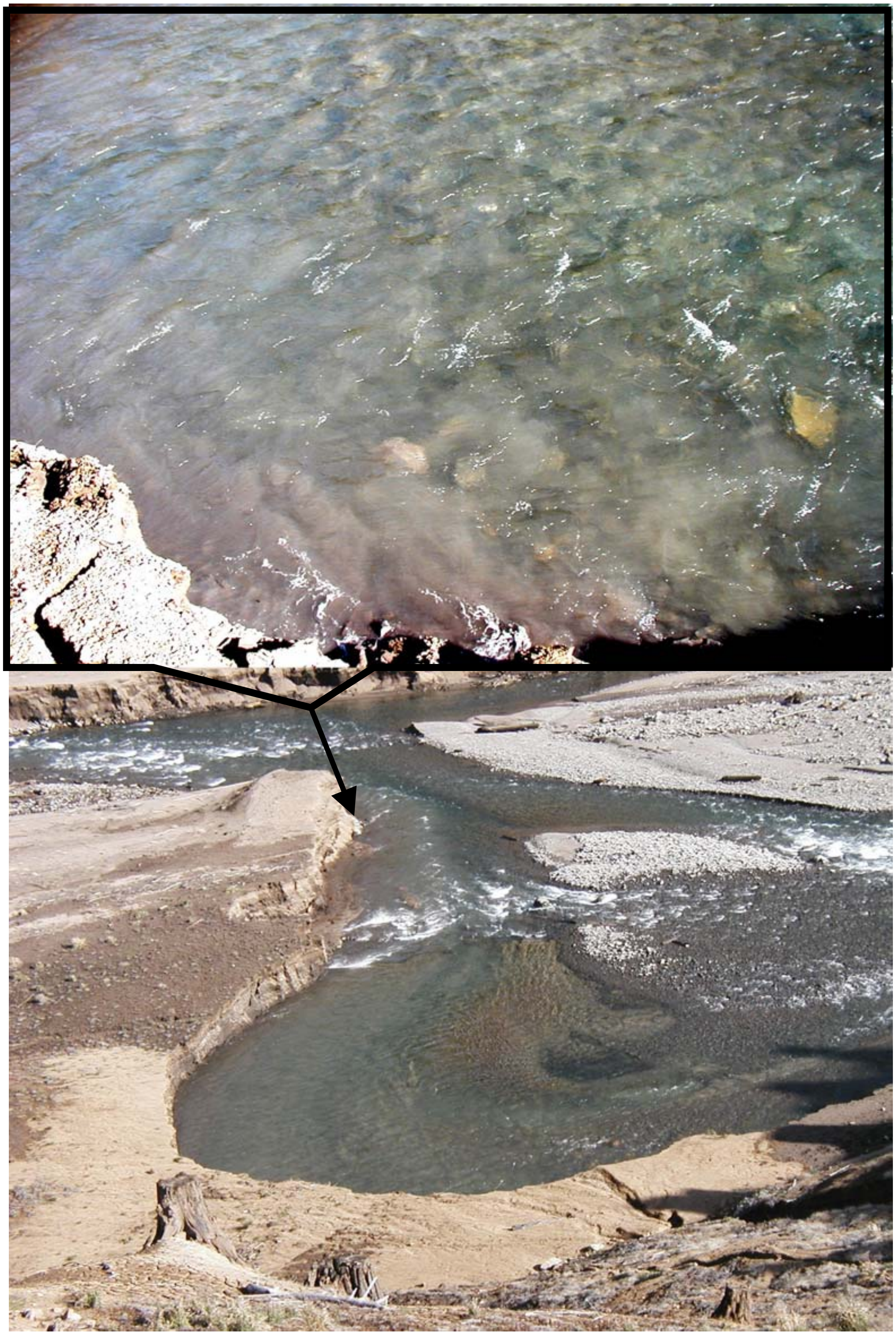

Figure 10 - Erosion along clay bank (bottom) – (top) close up showing suspension of clay material.

4. Lateral migration and downcutting of main South Fork McKenzie inflow channel during high inflows. Rapid rises in the pool elevation downstream create new control points upstream. Significant rapid erosion across the newly formed flood plain resuspends sediment into the residual pool. (Figure 11)

Figure 11 - South Fork McKenzie inflow to Cougar Reservoir - January 29 - 31, 2003. Photos by Patrick O'Brien (USACE) and Chauncey Anderson (USGS).

Adaptive management – changes in the reservoir operational plan

An outlet pipe connected to the Rush Creek drainage culvert failed during a storm in late January 2003, exposing the slope to flow from the culvert (Figure 12). A large portion of the slope below the outlet pipe failed. Releases to maintain the 1400 foot pool were immediately cutback so that the pool level could be brought up to 1450 feet, just below the elevation of the outlet pipe. The remaining slope supporting the drainage culvert was stabilized by holding the pool level at 1450 feet.

Figure 12 - Rush Creek drainage structure - slope failure January 30 - 31, 2003. Photos by Patrick O'Brien (USACE) and Chauncey Anderson (USGS).

The slope failure caused an immediate spike in the turbidity downstream of the reservoir of 1030 NTU on January 30, 2003. The turbidity level dropped to 450 NTU and fell to 83 NTU by February 3, 2003 (Figure 7). While the slope failure caused an immediate spike, channel downcutting and migration by the South Fork McKenzie from January 30 to 31, 2003 (Figure 11) resuspended a large amount of sediment contributing to the high turbidity observed downstream.

The pool is being maintained at this level until the bank can be stabilized. A permanent change in operation, which would maintain the pool at 1450 feet for the remainder of the construction period, is an option. If the pool is maintained at this higher elevation the following could occur:

- An increased risk of flooding the construction site by overtopping the cofferdam at 1495 feet during the construction season (13.7% vs. 7.8%) balanced with the cost of evacuation of the site versus the cost of repairing and stabilizing the slope.
- An increase in the relative time it takes to clear the reservoir of turbid water caused by erosion occurring within the reservoir. The volume of water the reservoir holds at 1450 feet is approximately 3 times greater than at 1400 feet. It would take longer to clear the reservoir of the turbid water, extending the duration of the turbidity downstream.

The effects on erosion and sedimentation processes within the reservoir by operation of the pool at the 1450 foot level versus 1400 feet are:

- A likely decrease in slope failures in the lower pool. Several localized slope failures were observed after the late January storm. Changes in pool elevation would be smaller for a 1450 foot pool given the higher storage capacity above 1450 feet.
- More of the exposed fine sediment deposits are covered at a 1450 foot level, thereby exposing less material to resuspension and transport downstream.

Post construction Cougar Reservoir operational planning

Some consideration should be given to developing a reservoir operational plan which would reverse some of the environmental effects of the elevated levels of fine sediment caused by the construction project immediately downstream of the reservoir. One effect is increased accumulation of fine sediment into salmonoid spawning gravels. Results of core samples taken of the spawning gravels in the South Fork McKenzie River below Cougar Reservoir and in the mainstem McKenzie River showed higher accumulation of fine sediments in the samples in the South Fork McKenzie than was present in the samples from the mainstem McKenzie River. (Stewart et al., 2002). These results suggest the accumulation has occurred over the 40-year time period in which the reservoir has been in place.

A post construction reservoir operational plan should include releases designed to reverse some of the fine sediment intrusion. When reservoirs are operated for flood control downstream, the releases are made to minimize as much as possible the effect of a flood which would other wise have occurred without the reservoir. Natural floods create a periods of high energy flow where the interstitial velocities within the gravel may become high enough to induce streambed movement and flush out fines which have infiltrated. Controlled releases of high energy flows from Cougar Reservoir after the construction project might help flush some of the fine sediments which have accumulated in the gravel bed during 40 years of reservoir operation.

Conclusions

Development of a reservoir operational plan for construction is a complex process involving many factors outside of water supply or minimum flow requirements. Short and long term environmental effects downstream of the reservoir as a result of releasing turbid water may be minimized by adoption of reservoir operational plans which provide the greatest reduction of erosion and fine sediment transport.

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Photographs courtesy of Chauncey Anderson, USGS, Portland, Oregon.